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The Impact of Agent Activation on Population Behavior in an Agent-based Model of Civil Revolt

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Abstract

In creating agent-based models of complex adaptive systems, the model designer must specify, as part of the design, the conditions and sequence with which agents activate – sensing their environment and updating their state. Activation can be synchronous (all agents execute simultaneously) or asynchronous, and the latter can be uniform (turn-based and shuffled), random, or Poisson (heterogeneous activation rate dependent on state). In a replication of a well-documented model of civil unrest, a statistically significant difference in emergent population behavior is demonstrated as a consequence of different activation patterns.

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Keywords: agent-based model; model design; replication; activation; updating

1. Introduction

Agent-based models have been proposed in a broad range of scientific domains as a method of simulating self-organizing systems. The popular ABM-building environment, NetLogo [1] includes a model library with over 300 applications across the fields of mathematics, statistics, and many physical and social sciences. Some 405 scholarly articles have been published in the past 15 months with the phrase "Agent-based Model" in the title.

Constructing such models requires a number of fundamental design decisions, such as:

- How many agents?
- How will agents move, if at all?
- What are the agents' vision?
- Will agents be connected in a network?

An additional key element of agent behavior that must be specified *may* be the activation scheme, sometimes referred to as 'updating'. This is simply the ordering of execution of the agents' objects' code. For two decades, ABM designers have known that different activation schema provide different results [2], [3], [4] in *some* models, but it is an open question as to whether this is a general phenomenon or one that appears rarely and produces little impact.

There are several activation schema. Initially, only *synchronous* or *asynchronous* activation schema (defined below) were considered. For programming applications before the advent of object-oriented languages, synchronous activation was the easiest to develop and the most straightforward algorithm to code. To achieve it, an array of entities would be interrogated one at a time in a loop, where the loop index is the array element number. Once the decisions have been recorded, the entire population would undergo a simultaneous state-change.

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Many early models, and, in fact, some that are broadly accepted today, use an unstated and simplistic activation process. NetLogo, as noted above, uses a turn-based activation in which the order of agent activation is shuffled in each turn – known as *uniform* activation. This can be changed in NetLogo, but it requires intentional modification of the code. Most important, however, is that a survey of the documentation of models in the NetLogo model library – those models submitted to the NetLogo sponsor by researchers across the domains – shows that most model builders do not explore different activation schema.

2. Agent-based Model Importance

While the original agent-based models were developed to explore abstract or theoretical issues, increasingly such models are offered as a means to understand and explore policy interventions or scientific issues. Recently published articles that received multiple (greater than five) citations in their first year of publication include studies on UK demographics [5]; cancer spread [6]; the US housing market loan crisis [7]; and the reliability of the scientific peer-review process [8].

But, if such models are to take on an important and abiding role in guiding decisions, if they are presumed to have some predictive relationship with real world social systems, they must conform to the basic tenets of scientific validity. One of the most important of these is the ability of subsequent researchers to replicate the results of original research.

At the same time that ABMs are growing in importance to decision-makers, a number of researchers and research communities have called for a standardization in the description of agent-based models [4], [9], [10]. In 2006, a group of 28 biologists and other life scientists proposed a "standard protocol for describing" agent-based models [10]. They propose a top level of three descriptive areas: overview, design concepts, and details – the 'ODD' framework. These are further subdivided into concept areas. In the overview area of each ABM description, they propose a segment on "process overview and scheduling" in which activation should be treated. They do not use the term 'activation'. In fact, the idea is further deconstructed into the scheduling of model processes and updating agents' state variables. The scheduling, they note, can be in continuous time or discrete, and the updating, which is a function of the scheduling, can be synchronous or asynchronous. They make no recommendations about examining these design choices for validity.

Grimm, et. al. [10] are strong advocates, however, of explicit descriptions of activation schema (scheduling and updating) as ABM research is presented. And, they elaborate on the most effective ways to present the scheduling of agents. In this, they mention (briefly), the use of flow charts and pseudo-code. Each has its advantages, but they expect individual researchers to choose the most appropriate. They claim that flow charts have a weakness in which they must 'correspond literally to the flow processes of the model' – with the potential of reducing clarity rather than improving it. More elaboration of this problem would help if the aim is to get all researchers on the same page. It is noteworthy, however, that these authors seem to encourage more close examination of the different ways to *present* activation than of the different ways to *implement* activation. Still, of all the standardization protocol proposals, this has the most explicit and detailed discussion of the concept of activation.

The most important aspect of the Grimm, et. al. article is its goal of facilitating replication in model-building. At the outset, the 28 authors state the purpose of developing protocols and a standard framework for model description is to enable subsequent researchers to extend investigations on different programming platforms (operating systems and modeling languages). The need for replication is so great that, in 2010, the European Social Simulation Association announced (in conjunction with Volterra Consulting) an annual prize of 500 Euros for the best example of rebuilding a published model with different technology. Very little has been written about this since 2010, however, and subsequent winners have not been announced on the Volterra Consulting website.

Is the choice of an activation scheme a critical element in achieving this replication? We set out to determine this by, first, completing the replication of an important ABM and then varying the activation scheme. It is clear that activation is not the only element that should be so examined – model scale, the type of random number generator, and agent heterogeneity (or lack of such) are also important considerations for would-be replicators.

3. A Model of Civil Revolt

- Epstein [11] proposed a model of civil unrest that was based on a theory that each individual would choose to become an active, violent actor (a 'stone-thrower' is the common interpretation) based on a number of decision variables:
- The individual's sense of grievance against his conditions
- The individual's belief in the legitimacy of the government
- The individual's proximity to other active individuals, and
- The individual's proximity to a police officer (who could arrest and jail him)

Epstein instantiated this model and, despite the simple rule set, demonstrated complex emergent behavior. His model showed 'burst' of violence that appear as localized outbreaks. In addition, the model showed that these bursts were heavily dependent on the jail term once arrested and the density of police officers.

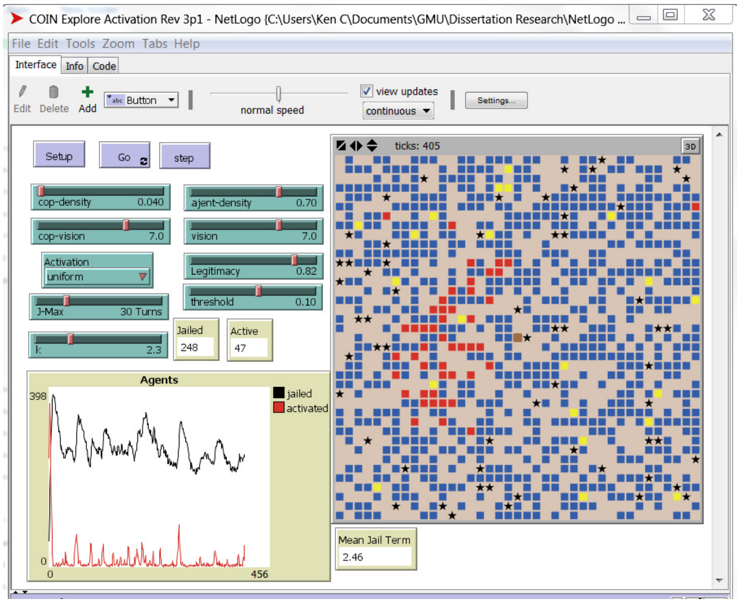

Figure 1. model visualization during a revolt outburst

We recoded the model described by the Epstein paper in NetLogo, and observed that the general behavior was as described in the original article. That is, an emergent behavior curve was demonstrated that was similar to the published curve in the Epstein model. Revolts appear as localized bursts of activity that occur when a large concentration of potential extremists (those with high grievance and who believe the government is illegitimate) appear in a location where there are (momentarily) few cops.

It is important to note that the Epstein model was chosen carefully. It is a rare instance in which the activation scheme is described explicitly, as well as a wide number of other model features and parameters. Thus, while we were successful in replicating Epstein's results, replicating a model in which these parameters were not published would be much more challenging. Just testing all combinations of known activation schemes described above could potentially overwhelm the research time available. And, it is possible that model builders could create, unwittingly, a novel activation method unlike any other tried earlier. If this were undocumented, replication would be nearly impossible.

4. Alternative Activation Schema for the Civil Revolt Model

According to the original article, the only activation scheme examined was uniform. Agents would update asynchronously, activating once per turn in random order. In the repeat instantiation described here, uniform activation was first examined. NetLogo creates straightforward commands such that agents are given a turn to move and choose revolt once per 'tick', but the order in which these agents execute these actions is shuffled. For this model, the details of activation are likely to be important because movement and, especially, the decision to change state depends on the movement and states of all the agents in the vicinity.

After the results were obtained with uniform activation, the model was re-evaluated using a synchronous and a random activation scheme. In the synchronous case, agents would move first and then sense their environment. They would count the cops and the active agents in their vision radius. At that point, they would make the active-passive decision and store it in a buffer. Once all the agents have made their decisions, the buffered decisions were applied. In random activation, agents chosen at random were moved and then they would decide whether to activate based on their new neighborhood. A 'tick' or turn was defined as complete when a full population-worth of agents had activated.

5. Outcome Behavior Metrics

There are numerous ways to describe the outcome qualitatively, but in the original article[11], Epstein has chosen a few quantitative measures: "waiting time" or the time between the arrivals of peaks and the height of individual peaks. Epstein defined a peak as an episode in which the number of 'active' citizens exceeds 50. That is, a peak begins on the turn when the active count exceeds 50 and ends when the active count falls below 50. (Note how valuable this precise description of his methods is in defining the quantitative outcome of his model.)

In replicating Epstein's behavior, we have chosen to redefine a peak threshold slightly to be three standard deviations above the mean value of the active population. This, of course, necessitates collecting the data for a complete run before the peak threshold can be calculated. We chose this redefinition to allow for a more general analysis of models at a wide range of scales. This allows us to examine, for example, model behavior if total agent population were twice or ten times the size of the published experiments.

Epstein reported that the frequency distribution of wait times was exponential. He showed this by conducting a linear regression of the logarithm of the frequency of wait times in each bin of a histogram versus the wait times. He reported an r^2 for this regression of 0.98. In our analysis of 10^6 runs, we achieved nearly-identical results, with an r^2 of 0.97. The difference in the slope and *y*-intercept can be explained by the fact that we adopted a different threshold (3 σ) for the definition of a peak. That is, with a different threshold, there will be a slightly different number of 'peaks' and a different time between these peaks. The figure shows, however, that the statistical behavior is identical to the Epstein model.

In addition to providing confidence that we have effectively replicated the original model, the two measures – wait time and peak height – provide valuable quantitative measures of model behavior. Our goal to demonstrate whether activation changed model behavior could be put to a statistical test with these measures.

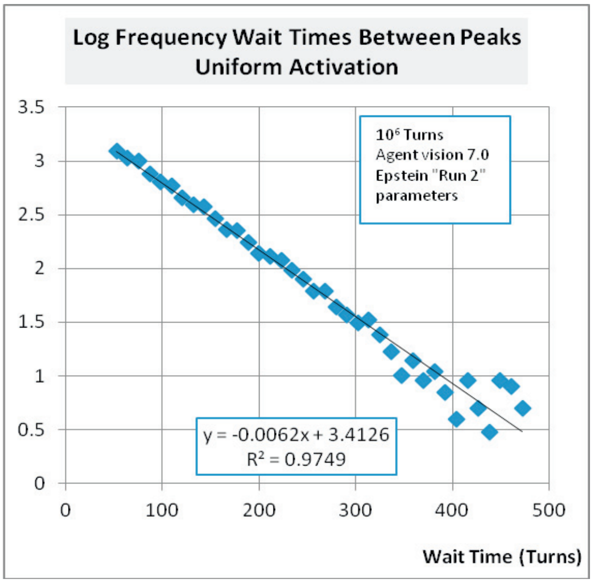

Figure 2. linear pattern in log of frequency of wait times between peaks

6. Experimental Method: Examine Two Additional Activation Schema

Epstein examined only uniform activation. In such a scheme all citizens and cops are activated once per turn, and the order in which they are activated is shuffled before they are activated. Activation consists of movement, arrest (in the case of cop-agents), and for non-cop, non-jailed citizens, deciding what state they will change to (active or non-active). In order to make the latter decision, citizens must sense their environment, which consists of counting the currently active citizens and the cops within their vision.

Needless to say, if these actions were performed in a different order, the results might be different. To examine this prospect, we re-arranged the model to evaluate two different activations schema, *synchronous* and *random*.

In synchronous activation, all agents undergo a movement phase at the beginning of the turn. Citizens and cops move in this model by selecting a vacant position within their vision and moving to it. Once they move, citizens sense the environment (count active citizens and cops) and make a decision whether they will activate in the next turn. This decision is placed in a 'buffer'. Of note, however, their count of active citizens only includes those that were active at the end of the last turn. Cops will arrest an active citizen once they move, but only a citizen whose state is already active.

Random activation is conducted similar to uniform activation (agents move, decide, and change state once they are activated, and they are inert at all other times), but there is no enforcement of the once-per-turn rule. Thus, activation consists of selecting an agent (cop or citizen) at random and executing all the activation functions (move, then sense, then act – arrest or chose new state). The random activation process eliminates the concept of a 'turn', which opens a question of how to do side-by-side comparisons with the two other schema. To support these comparisons, a 'turn' is defined as the number of random activations equal to one complete population of agents. This will maintain the same 'scale' when model output is compared.

Table 1. Run Parameters

Parameter	Value	Parameter	Value
Landscape	40 X 40 Torus	Citizen Density	0.7
Maximum Jail Term	30	Cop Density	0.04
Legitimacy	0.82	Citizen Vision	7
Arrest Probability Constant, *k*	2.3	Cop Vision	7

At least one researcher has used this definition of a turn in random activation [12], deeming a full turn as a "Monte Carlo update". The motivation is straightforward: on average each agent will be activated once per turn. About half of the agents will not be activated at all, and it will be extremely rare that an agent will be activated more than five times. (This is based on simple rules of Bernoulli trials.) As we noted in other matters, the definition of a turn in models that use random activation is a key specification required for replication of results and comparison of output.

7. Behavior Space Explorations

The behavior of the model was explored for the three activation schema at the initial, "run 2" parameters from the Epstein article. These are:

As the behavior was explored, some differences appeared between the activation schemes as observed in the waiting times and the peak heights. It was discovered that, as the citizen vision increases, the differences become more pronounced. As the purpose of this experiment was to determine if there were *any* differences as a result of activation, the slightly larger citizen vision of 8.2 was chosen for further exploration. The value 8.2 was chosen because at this level differences in impact from changing activation became the most pronounced. All of the subsequent synchronous activation trials were conducted at the value of 8.2.

In evaluating these sample average wait times, it became apparent that the model was not producing behavior consistent with the Central Limit Theorem. That is, as the sample size (the number of peaks) was increased, the variance of the sample average did not go down. This suggests that a non-parametric test is appropriate, as the population average and variance may be undefined.

The appropriate non-parametric test to determine if multiple samples are generated from the same population is the Kurskal-Wallis test. Using a K-W test of both waiting times and peak heights, we can reject the null hypothesis that all three were drawn from the same population with a p-value of 2.8 X 10^{-6} and 7.6 X 10^{-5} respectively. This allows us to reject the null hypothesis that all three were drawn from the same population, but as there are only three samples (for each of the two output variables), we can do a pair-wise test, the Fisher Exact Test. The results are shown in Table 2.

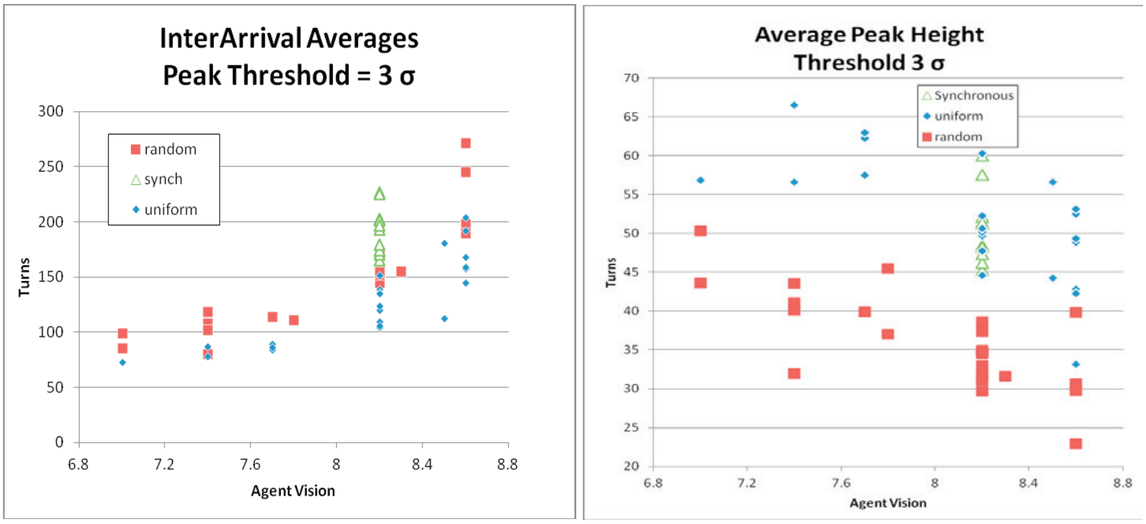

Figure 3. average interarrival times and peak heights for revolts vs. agent vision

Thus, for five out of the six pairwise comparisons, we can reject the null hypothesis that the samples were drawn from the same population and activation made no difference. Only in the uniform-synchronous comparison, and only in the height of the revolt peak heights are we unable to discern a difference between the choice of activation.

Table 2. p-values for Fisher exact test

Waiting Times		*Peak Heights*	
Comparison	p-value (Fisher exact test)	Comparison	p-value (Fisher exact test)
Random-Uniform	0.00021**	Random-Uniform	4.1 x 10^{-5}**
Random-Synchronous	0.00011**	Random-Synchronous	0.00011**
Uniform-Synchronous	0.00011**	Uniform-Synchronous	0.315

8. Conclusions

With the establishment that activation makes a clear difference in at least one policy-centric model, a compelling case can be made that ABM researchers should fully describe their activation scheme if they are to guide other researchers in proper replication of their models. This means that the sequence of events in the code (movement, environment-sensing, and state-change) needs to be explained explicitly in order that subsequent researchers can replicate the experiment. The Epstein model was chosen specifically because it is an excellent example of such specification.

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